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Mesoscale models in wind energy: A quick guide

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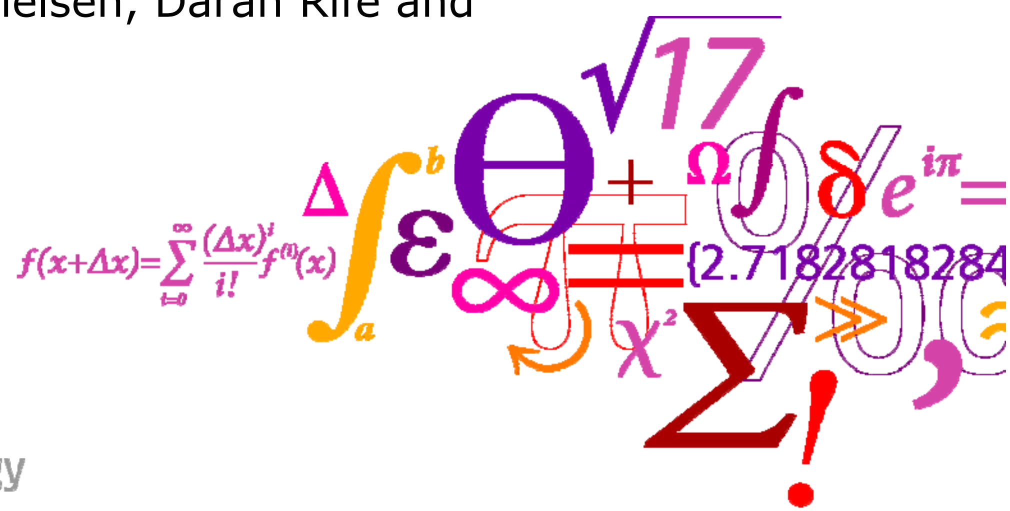
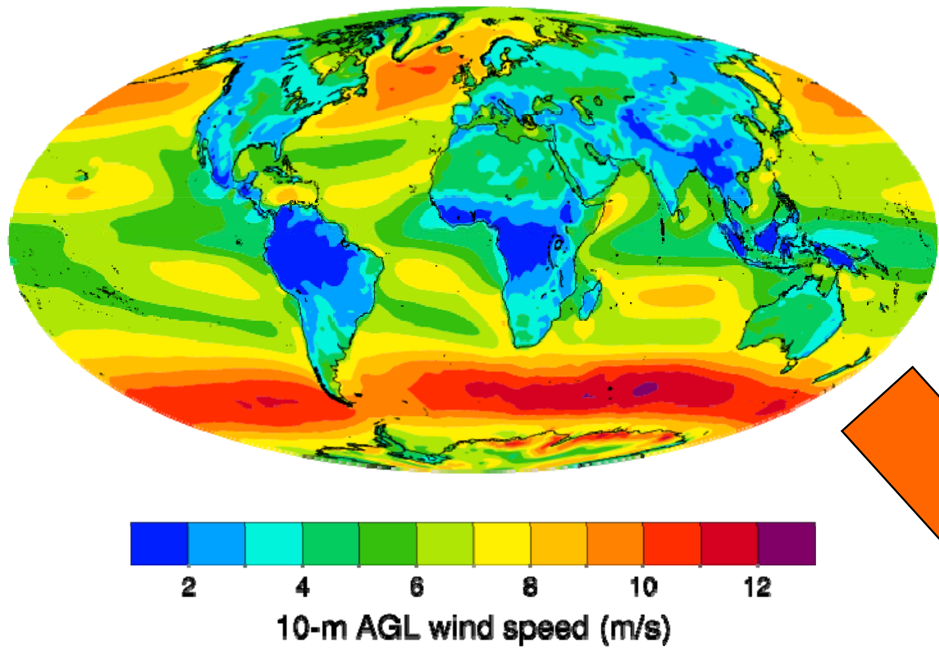
Jake Badger, Alfredo Peña, Xiaoli Larsen, Claire Vincent, Caroline Draxl, Mark Kelly, Joakim Nielsen, Daran Rife and Emilie Vanvyve



Outline

- The problem – an introduction
- The use of atmospheric mesoscale NWP models in wind energy applications
- Wind resource estimation
  - Importance of resolution
  - …
- Conclusions

ERA Interim reanalysis averaged winds (1989-2009)



Climate (Atmospheric reanalysis) Models → Resource prediction at the wind farm level

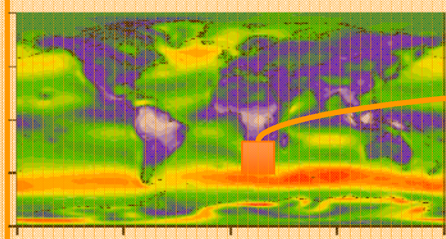
?

Weather (Numerical Weather Prediction - NWP) Models → Power forecast at the wind farm

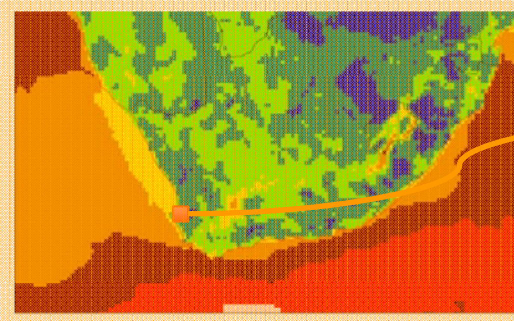
wind farm

Typical downscaling steps

Global



Regional



Local

Mesoscale modeling
KAMM, MM5, WRF, etc.

Microscale modeling
(WAsP, CFD, etc)
or statistical technique

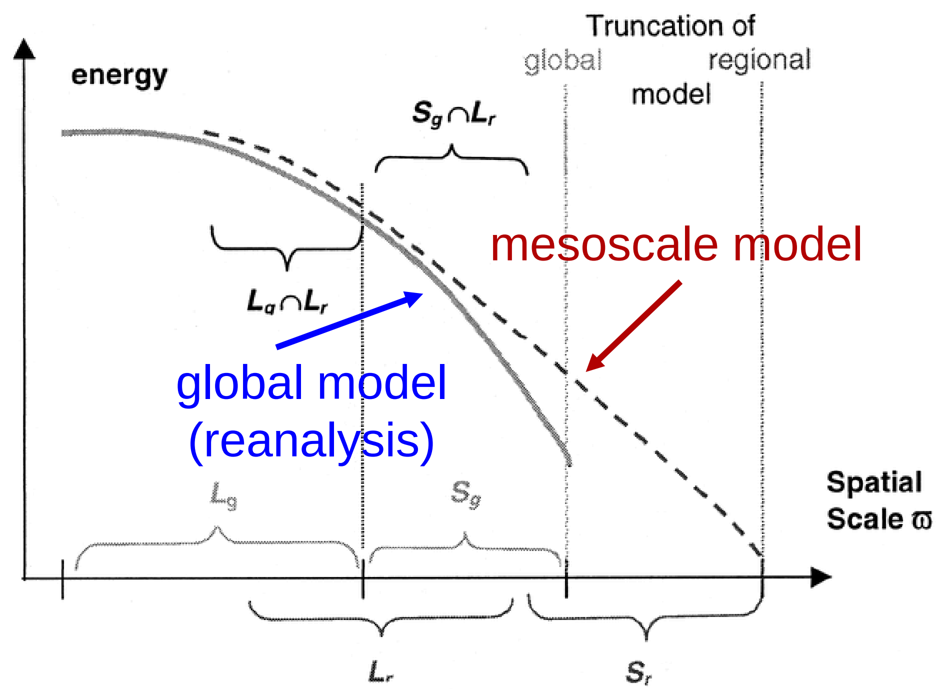
Dynamical downscaling for wind energy resource estimation

For estimating wind energy resources, mesoscale model simulations are:

- Not weather forecasting, spin-up may be an issue
- Not regional climate simulations, drift may be an issue

For this application:

- We "trust" the large-scale reanalysis that drives the downscaling
- We need to resolve smaller scales not present in the reanalysis



von Storch et al (2000)

What is an atmospheric analysis?

Data Assimilation merges observations & model predictions to provide a superior state estimate.

$$\frac{\partial x}{\partial t} = \text{dynamics} + \text{physics} + \Delta x$$

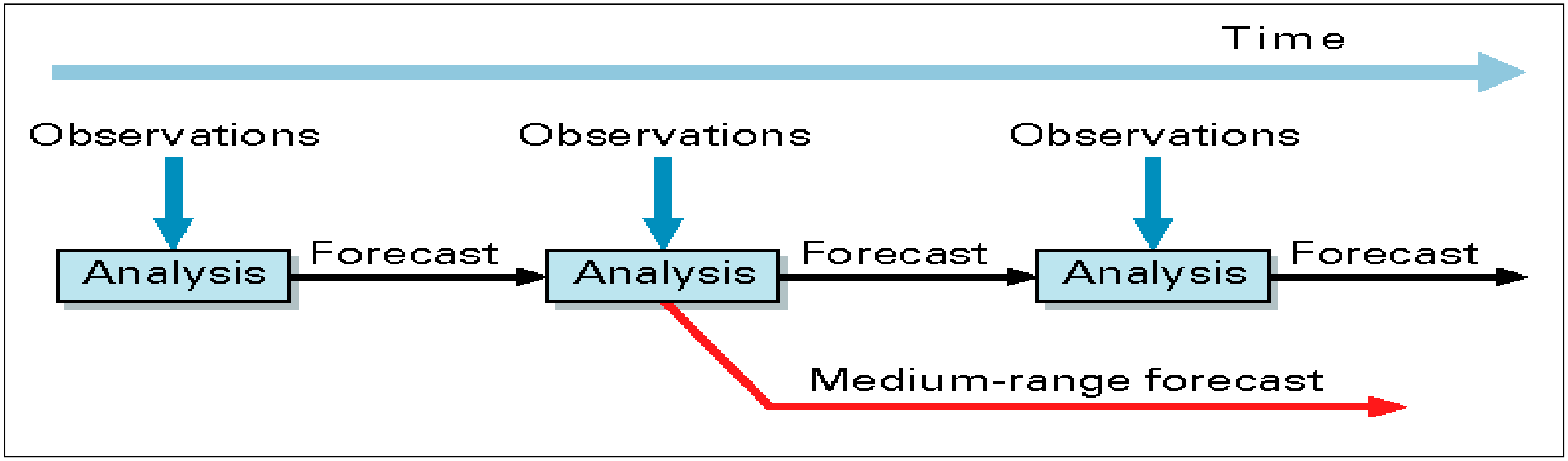
Data assimilation term

It provides a **dynamically-consistent** estimate of the state of the system using the best blend of past, current, and perhaps future observations.

Analysis products are provided by most major numerical weather prediction (NWP) centers. For example NCEP (USA), ECMWF (EU-UK), JMA (Japan).

Kevin Trenberth, NCAR & ECMWF 2009

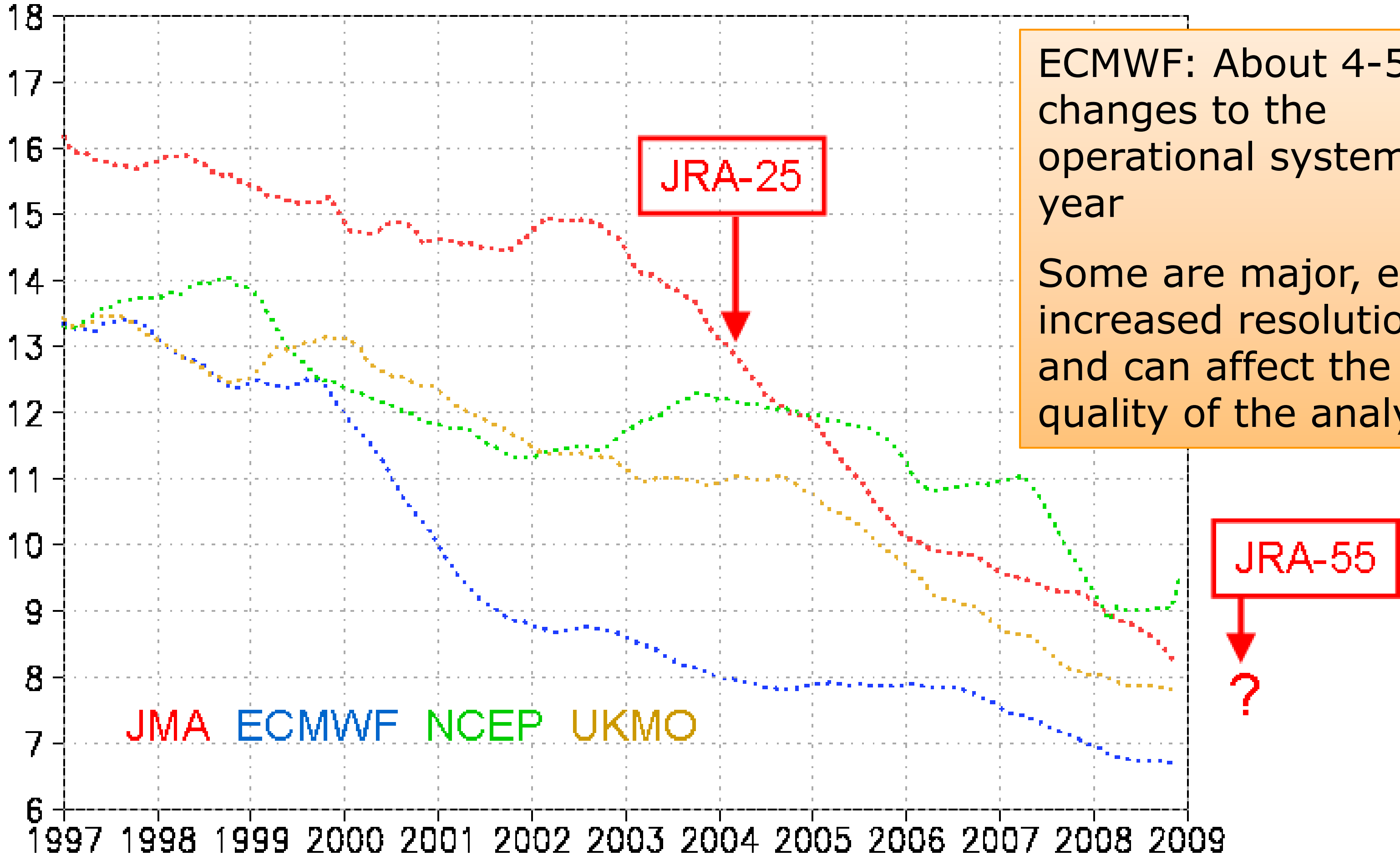
Operational Data Assimilation systems



- The observations are used to correct errors in the short forecast from the previous analysis time.
- Every 12 hours, ECMWF assimilates 7 – 9,000,000 observations to correct the 80,000,000 variables that define the model's virtual atmosphere.
- This is done by a careful 4-dimensional interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.

Kevin Trenberth, NCAR & ECMWF 2009

NWP models and data assimilation continues to improve



ECMWF: About 4-5 changes to the operational system per year

Some are major, e.g. increased resolution, and can affect the quality of the analysis

Operational forecast scores of major NWP centers. RMSE of geopotential height at 500hPa in NH (m) for 24-hour forecasts are displayed. The scores of forecasts have improved over time.

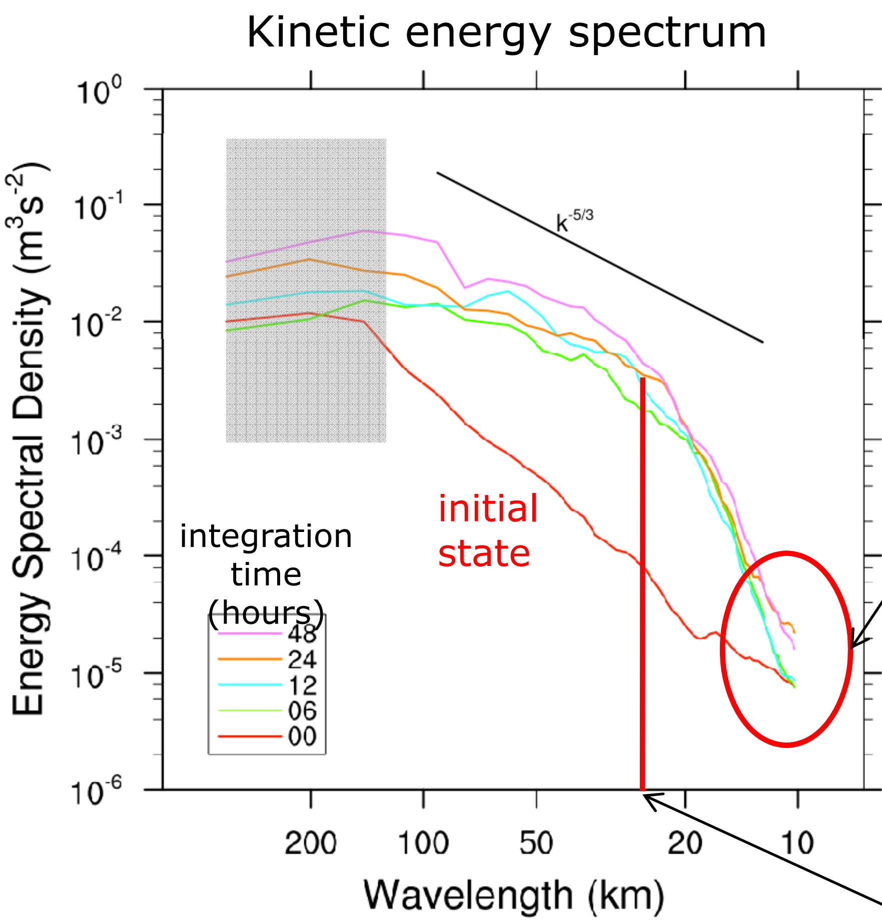
Kevin Trenberth, NCAR & ECMWF 2009

Analysis vs. Reanalysis

- **Reanalysis** is the retrospective analysis onto global grids using a multivariate physically consistent approach with a **<u>constant</u>** analysis system.
- Newer reanalysis products provide a consistent dataset with state of the art analysis system and horizontal resolution as fine as that of real-time operational analysis. (❖ are freely available)

Reanalysis	Horiz.Res	Dates	Vintage	Status
NCEP/NCAR R1❖	T62	1948-present	1995	ongoing
NCEP-DOE R2❖	T62	1979-present	2001	ongoing
CFSR (NCEP)❖	T382	1979-present	2009	thru 2009, ongoing
C20r (NOAA)	T62	1875-2008	2009	Complete, in progress
ERA-40	T159 (0.8°)	1957-2002	2004	done
ERA-Interim	T255	1989-present	2009	ongoing
JRA-25	T106	1979-present	2006	ongoing
JRA-55	T319	1958-2012	2009	underway
MERRA (NASA)❖	0.5°	1979-present	2009	thru 2010, ongoing

Spin-up and resolution effects



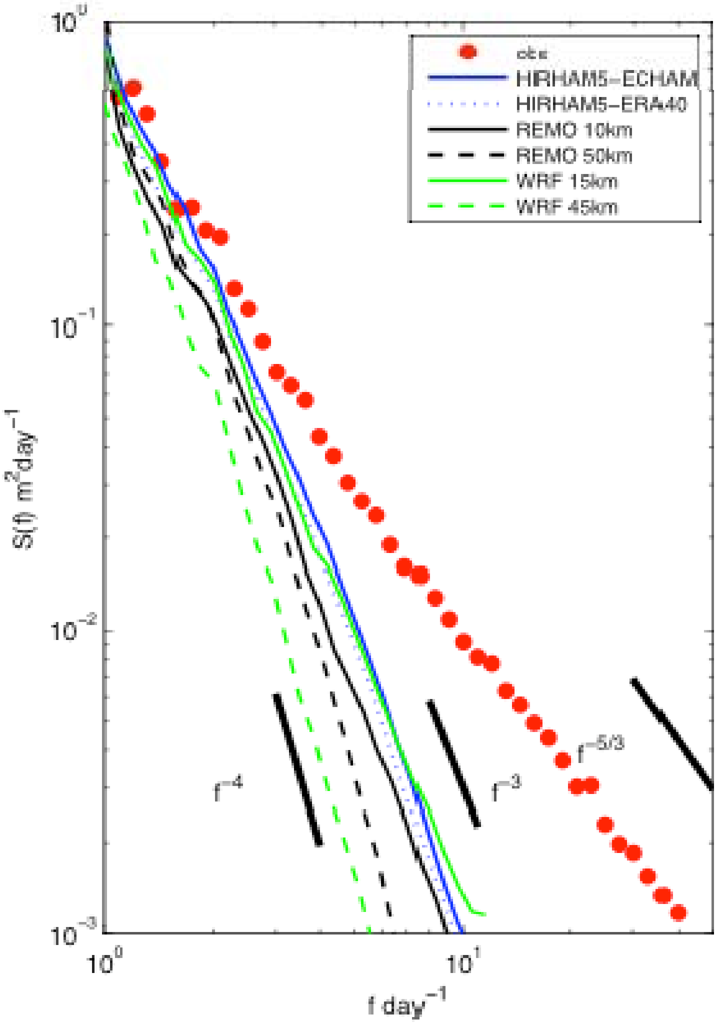
Downscaling run 5 km horizontal resolution grid over Northern Europe

Time required to build up mesoscale structures: ~24 hours

This length depends on domain size, wind regime, orographic complexity and details of the model used.

Effective resolution ~7 x grid spacing, depends on model numerics

Resolved temporal structures from various mesoscale model simulations



Time spectra of wind speed at Horns Rev (Denmark) from observations of various model simulations

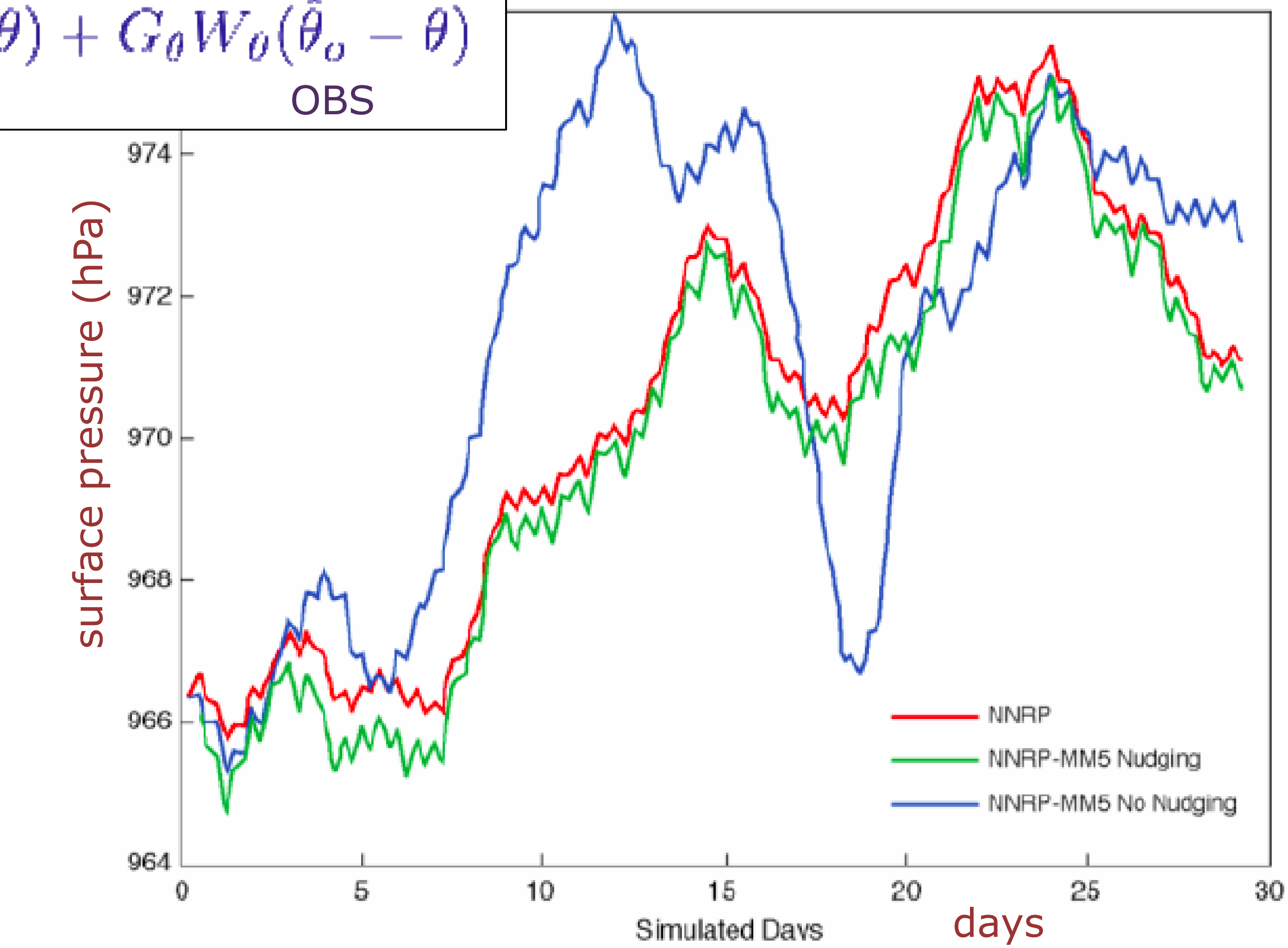
Xiaoli Larsén et al. 2011

Choice of coupling method is important

nudging term

$$\frac{\partial \theta}{\partial t} = F(\theta) + G_\theta W_\theta(\hat{\theta}_o - \theta)$$

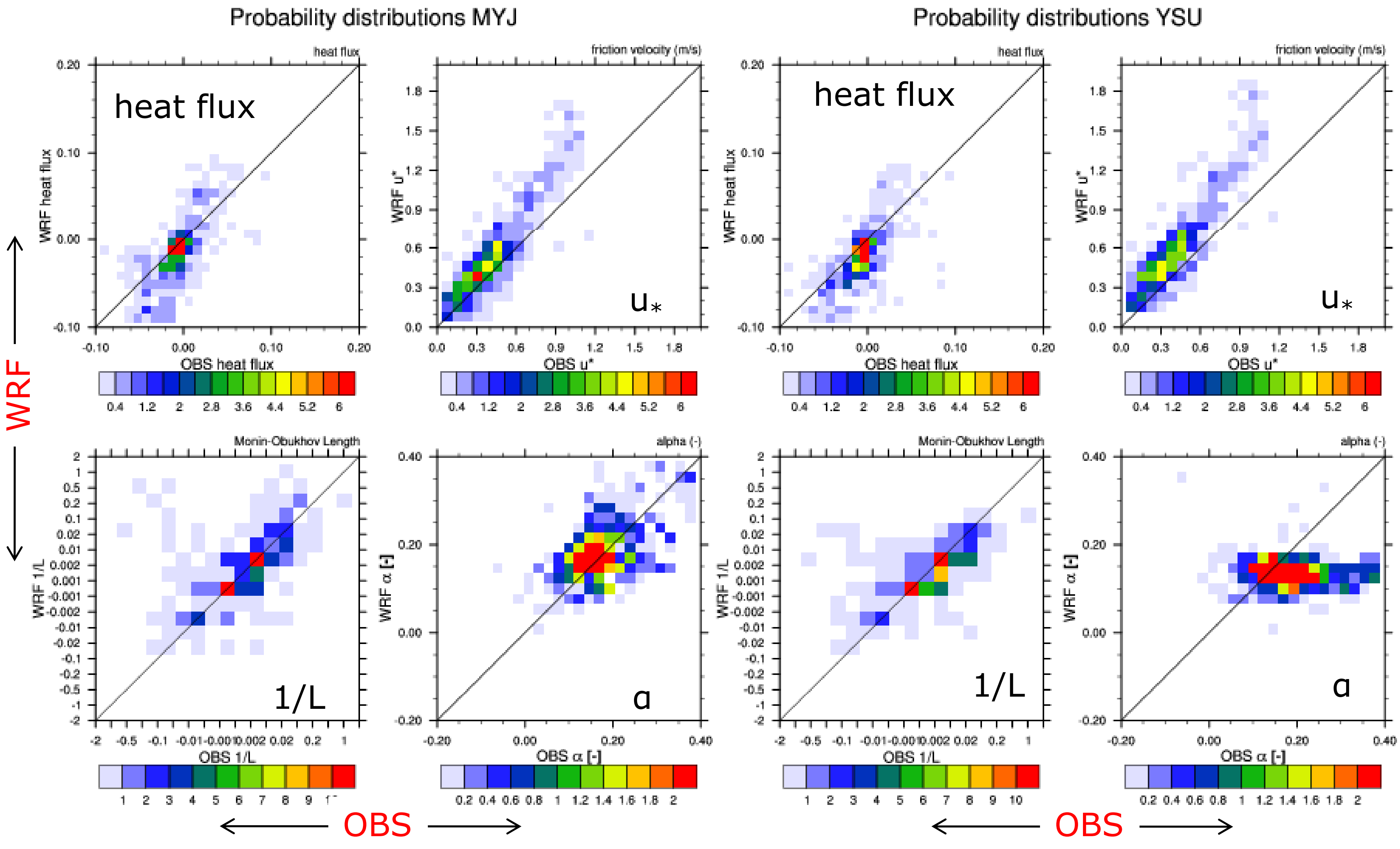
OBS

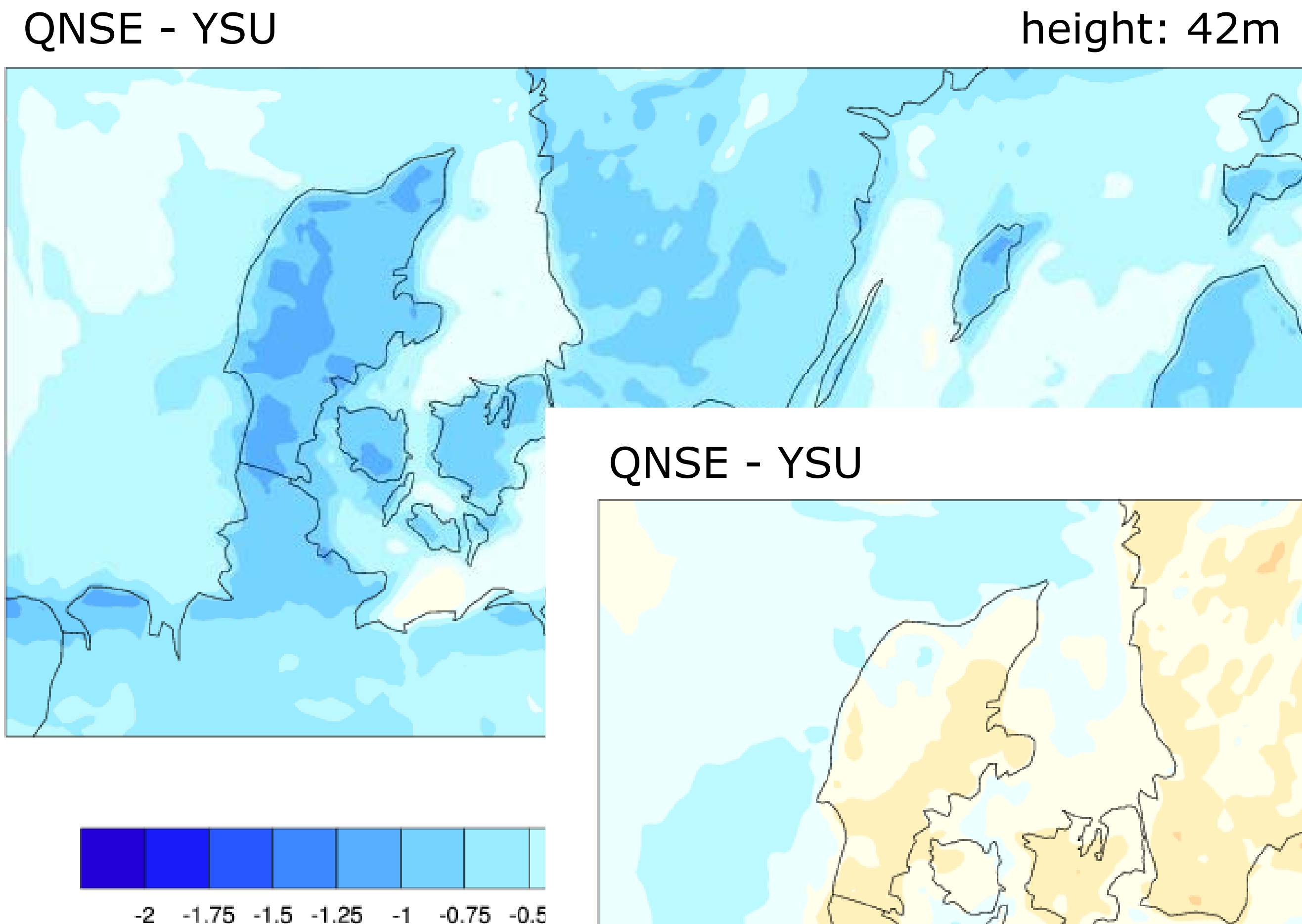


Domain-averaged surface pressure for a MM5 run over the Pacific Northwest (USA) - from Clifford Mass, Univ. of Washington

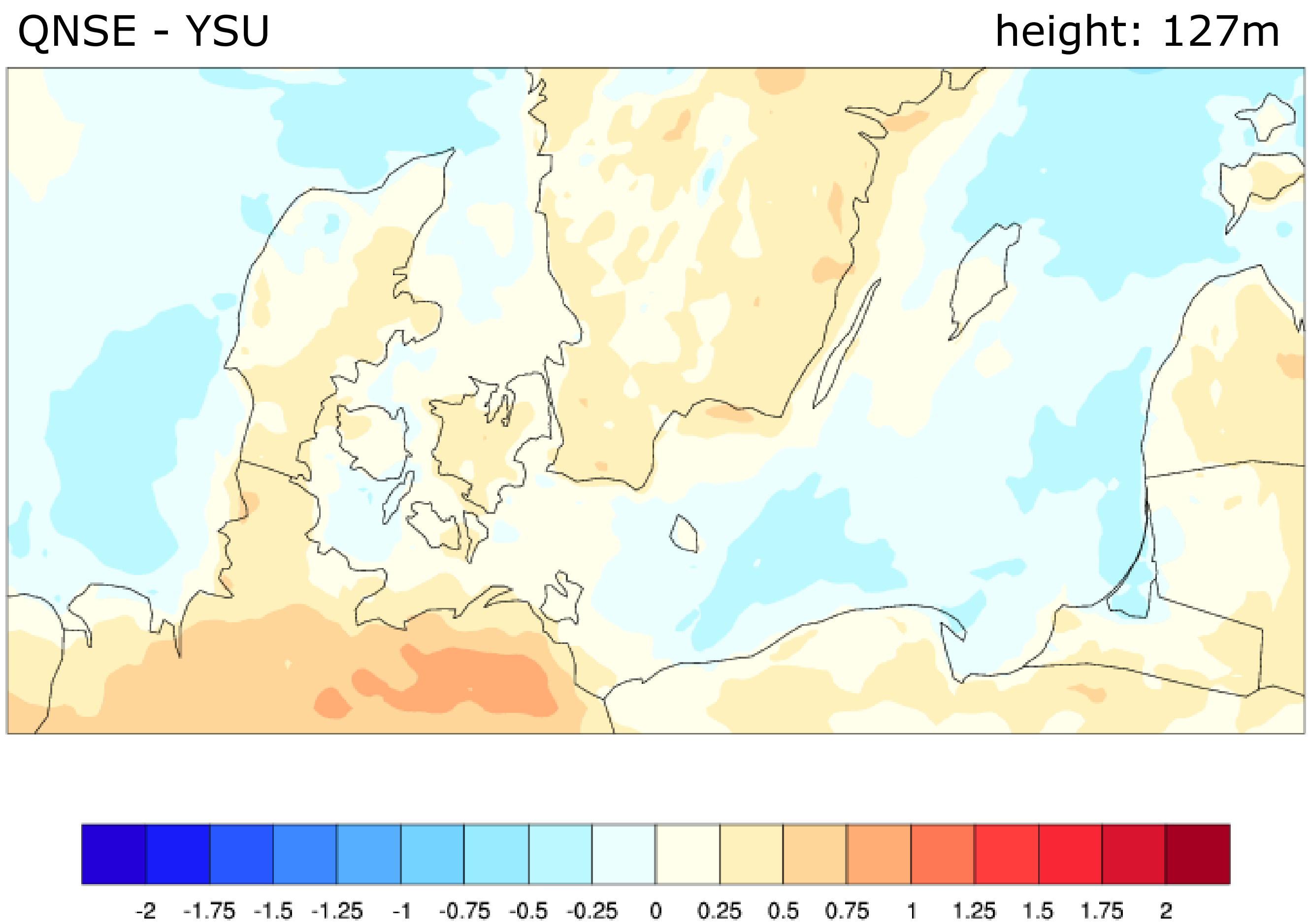
Choice of parameterizations is important

$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2}\right)^{\alpha}; \text{shear exponent; 10-60 m}$$



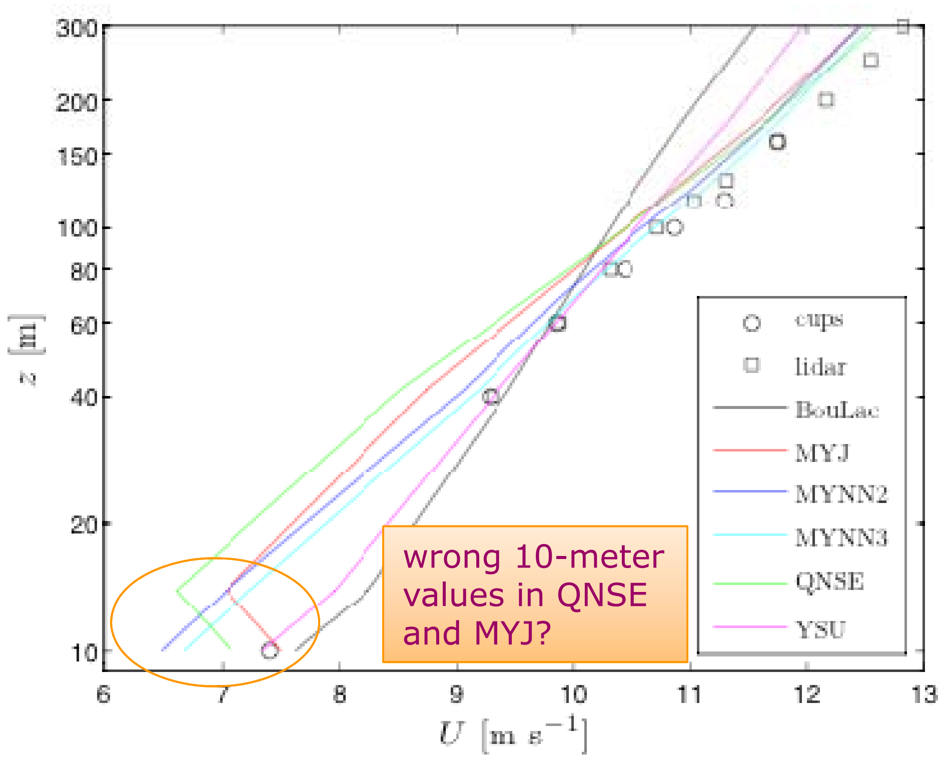


Monthly-mean (Oct 2009) differences in wind speed – 2 PBL schemes



Due to diffs in vertical shear among simulations with different PBL schemes: different over land and ocean

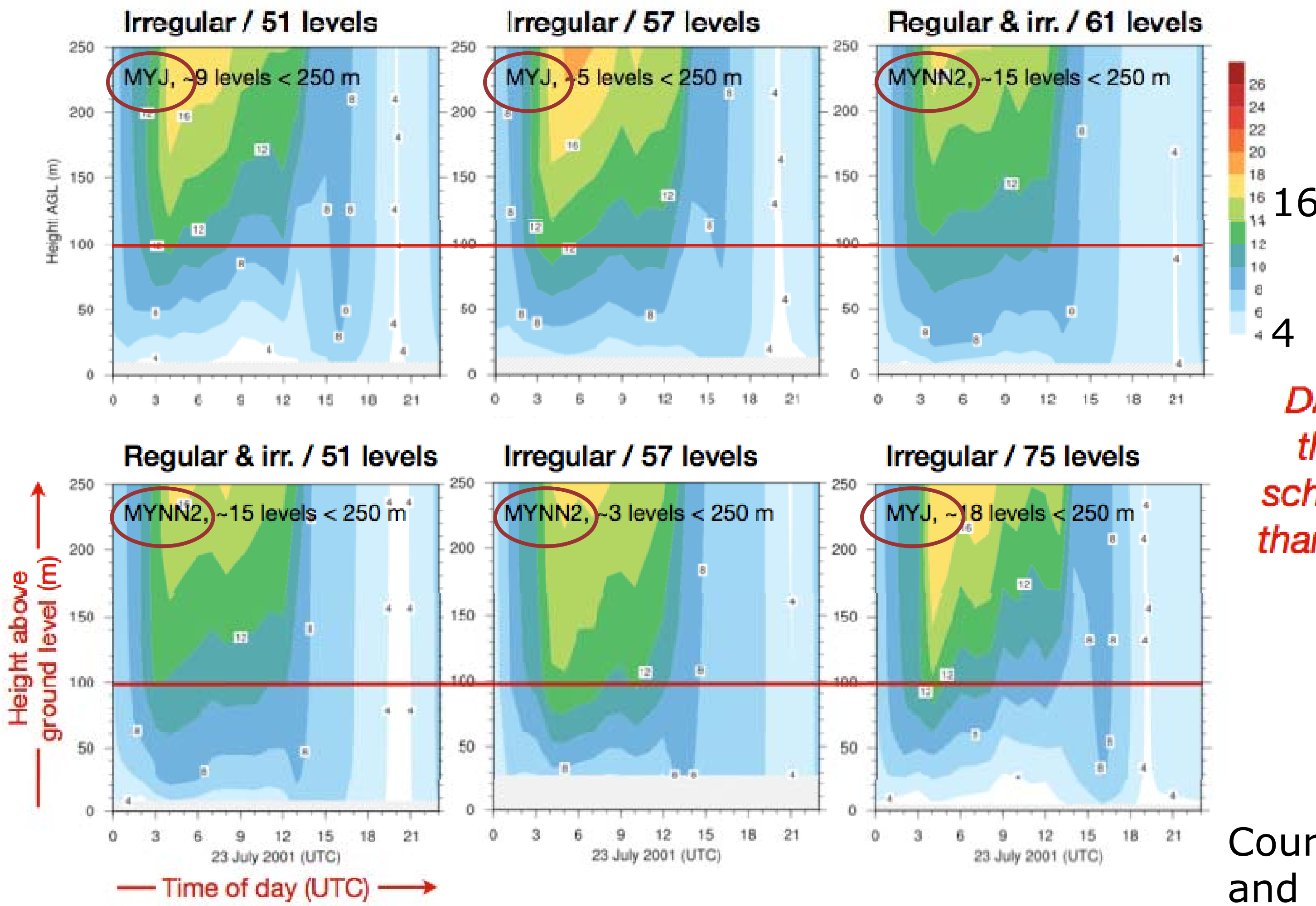
Comparison with Cups and Lidar data (Høvsøre, October 2009)



WRF versus observed wind speed measurements – all sectors

Effect of number of vertical levels and vertical resolution

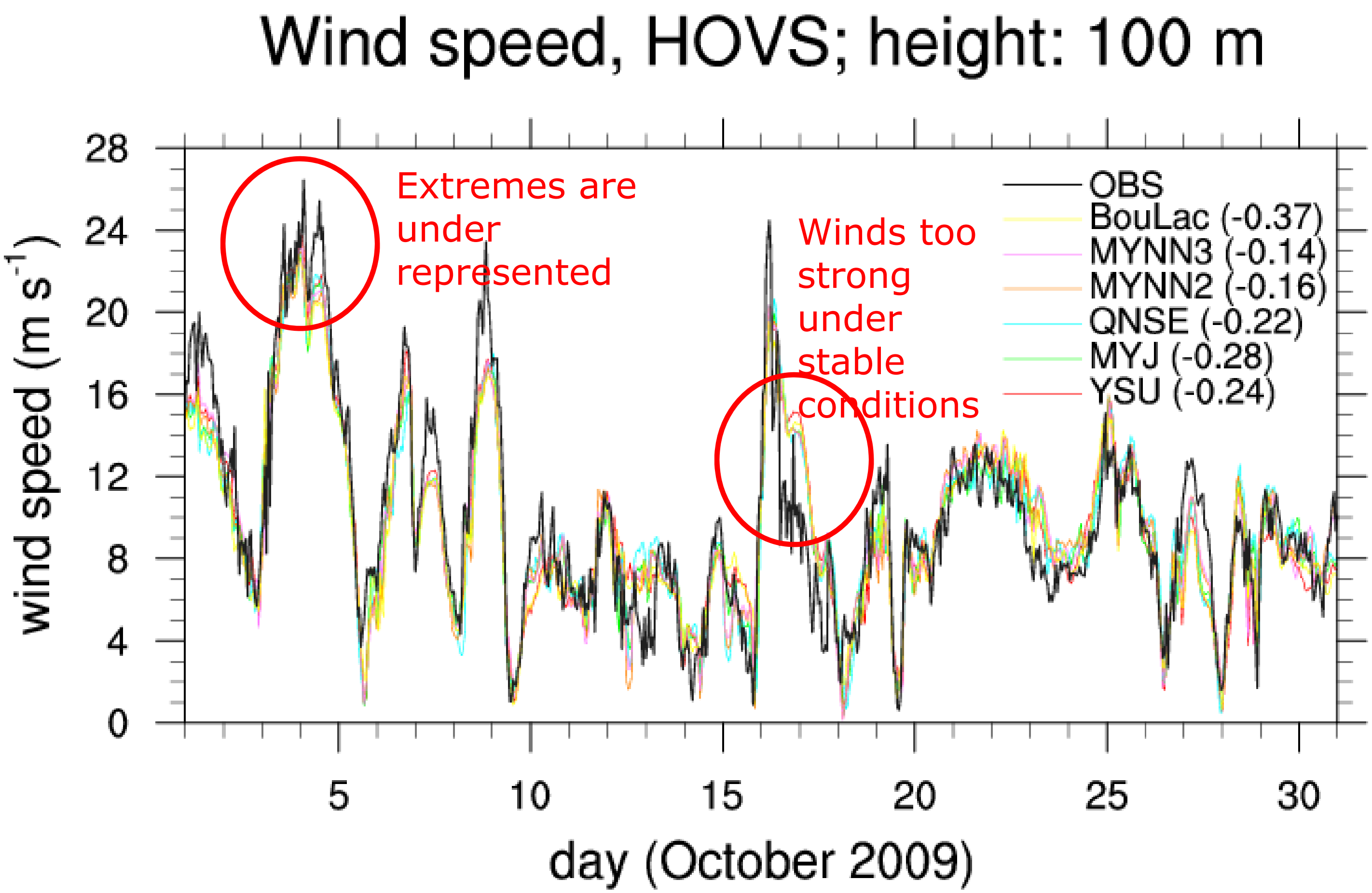
- Example results: wind speed (m/s) at Lamont OK on 07/23/2001



Case with a strong low level jet east of USA Rockies

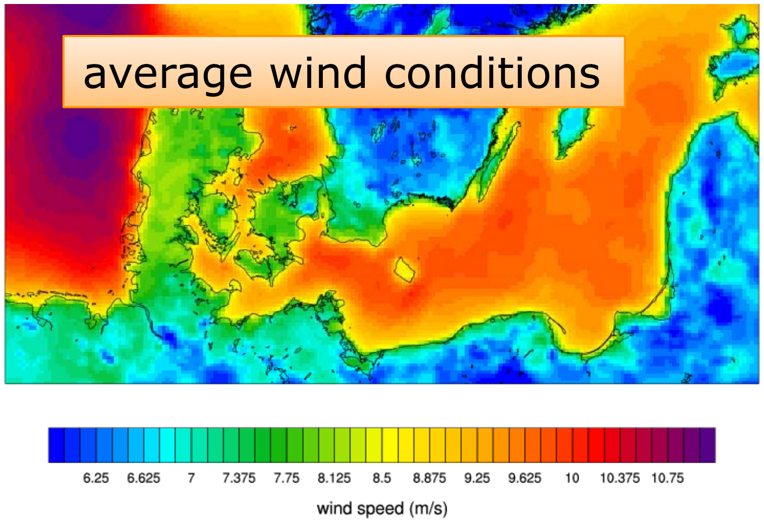
Differences due to the different PBL schemes used rather than number of levels

Courtesy of Daran Rife and Emilie Vanvyve, NCAR, USA

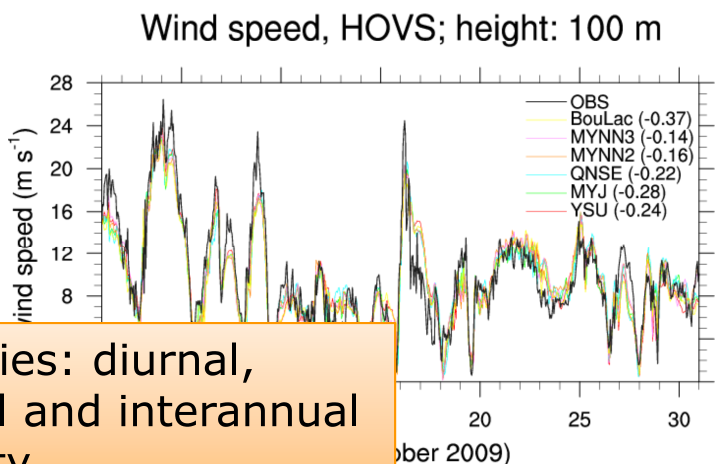


How do we use the knowledge about the errors in the simulation to device a better coupling strategy?

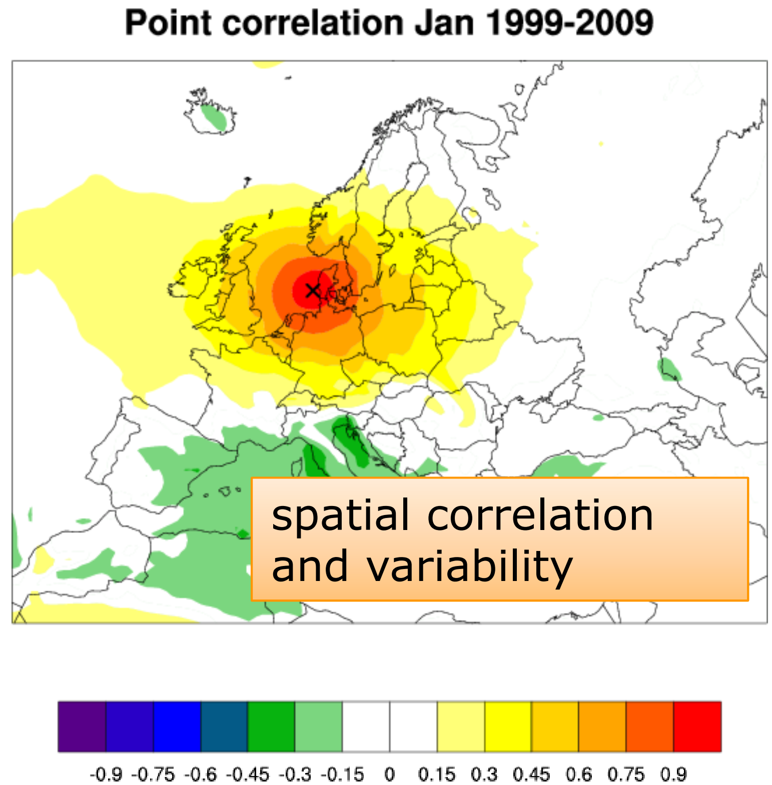
Dynamical downscaling applications



average wind conditions



time series: diurnal, seasonal and interannual variability



spatial correlation and variability

Studies of other wind-related atmospheric conditions: icing, severe temporal variability, predictability, etc.

Summary

- Atmospheric mesoscale models are used for both wind power forecasting and wind resource assessment.
- **Analysis** are **reanalysis** products are not equivalent, which to use will depend on the application; but, **reanalysis** are preferred for dynamical downscaling studies because of improved temporal consistency.
- Impact of the use of the various reanalysis products on wind resources at the mesoscale and local scale remains an unpublished issue.
- Grid nudging is also recommended. Its impact will depend on domain size, topographic complexity, model physics, etc.
- Beware of use of data assimilation: assimilated data cannot be used for further validation!
- Impact of domain size and resolution: determines scales resolved by mesoscale model, but it is more than just the grid spacing.
- Impact of choice of parameterizations: large, will depend on climate regime
- **Validation is a must,** especially with high quality **wind profiles**. 10-meter wind measurements should be avoided.
- How do we use the knowledge about the errors in the simulation to device a better coupling strategy?